The cost of meeting the Kyoto Protocol

Dealing with the carbon surplus in Russia and the Ukraine

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Abstract *Estimates the cost of meeting the Kyoto Protocol with an energy-economic optimization model. Special focus is on the Russian and Ukrainian and the potential implications of the US decision to withdraw from the Protocol. Finds that the carbon permit price can be expected to drop substantially due to US withdrawal. In fact, the aggregated emission target could be met in the absence of US participation. However, Russia and the Ukraine could be the dominant sellers of emission permits and they could increase the permit price. Clearly no climate benefits would result from trading emission permits that do not correspond to real reductions in* CO_2 *emissions. EU countries, Japan and Canada are not likely to be supportive of paying billions of dollars that do not result in emission reductions. One way of dealing with the Russian and Ukrainian surplus is to negotiate more stringent targets for subsequent commitment periods early, and to allow banking. The model suggests that, under these conditions, early action and banking do take place.*

Introduction

The 1997 Kyoto Protocol to the UN Framework convention of climate change (UNFCCC, 1992) contains legally binding greenhouse gas (GHG) emission reduction targets for developed countries, the so-called Annex 1 parties. The Protocol allows the creation of systems for emissions trading in which countries exceeding their target levels can remain in compliance by purchasing surplus permits from other Annex 1 countries (Article 17). This option was highly debated during the negotiations, partly since it can allow trading with no "real" emission reductions.

The Protocol requires the Russian Federation and the Ukraine to stabilize their emissions at their 1990 levels. However, during the last decade a 400 MtC yr^{-1} carbon surplus (normally referred to as hot air) has been created in these countries because their GHG emissions have dropped by 39 percent between 1990 and 1998. The main reason for this reduction is the economic disarray, which followed the collapse of the Soviet Union and central planning (Victor

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et al., 2001). Experts from the Russian Government estimate that about 60-70 percent of the emission reductions in the energy sector during the last decade were attributed to economic decline, about 8-12 percent to initiation of institutional reforms in the energy sector and the rest due to wider use of natural gas and structural changes in the economy (Mastepanov *et al.*, 2001), although it is not clear how they estimated these numbers.

Estimates of the marginal cost of meeting the Kyoto Protocol domestically in Annex 1 countries range between marginal abatement costs close to zero and as high as 1,200 US$ tC^{-1} (see for example the special issue of the Energy Journal, May 1999, which reports cost of compliance to the Kyoto Protocol for 12 different models affiliated to the Energy Modelling Forum, Weyant (1999)). However, the upper end range here is clearly extreme and most studies that allow trading end up with a permit price in the range 20-150 US$ tC^{-1}. However, the permit prices are expected to be sharply lower due to the withdrawal of the USA from the Kyoto Protocol, because the demand for emission allowances would be reduced without US participation (see, e.g. Nordhaus, 2001). The revenues to Russia and the Ukraine associated with the sales of the emission allowances would similarly decrease. There is concern that the price might collapse to very low levels, since it is possible that the required CO_2 reduction during the first commitment period, 2008-2012, would be less than or at least close to the carbon surplus in Russia, the Ukraine and Eastern Europe.

There appear to be several ways to prevent a large permit price collapse, including:

- Russia and the Ukraine can act as oligopolists, they are to some extent price makers and not price takers. Their goal would be to maximize their revenues from the sales of emissions allowances or reduce the future cost by banking all or some of their carbon surplus.
- The European Unioun (EU) countries may not find it politically acceptable if the Kyoto commitments were to be met by trading with hot air.
- The incentives for not selling and buying emission permits may increase if the second commitment period is negotiated before the first commitment period begins.
- The price would not drop if the USA were to rejoin the Protocol before 2008.

The aim of this paper is fourfold:

(1) Estimate the carbon permit price with and without Annex 1 trading with the USA ratifying the Protocol.

(2) Estimate the carbon permit price with competitive Annex 1 trading without the USA ratifying the Protocol.

(3) Estimate the carbon permit price without the USA ratifying the Protocol and with Annex 1 Former Soviet Union acting as oligopolists.

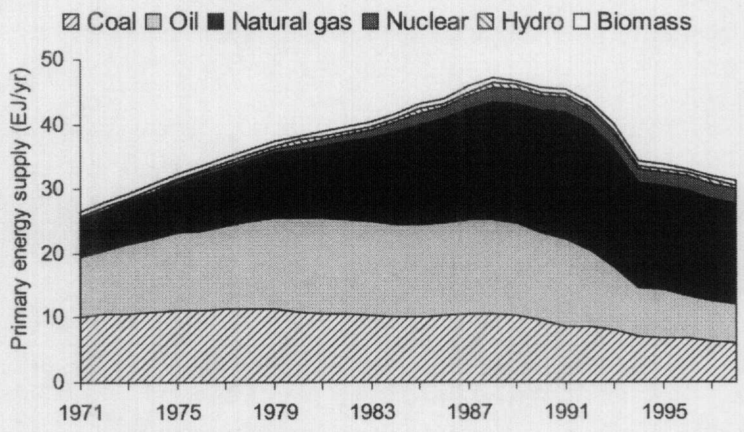
(4) Analyse how early negotiations and agreement on more stringent targets in the subsequent commitment periods could affect abatement policies and permit prices during the first commitment period.

A global energy-economic optimisation model (linear programming) with six regions, EU, A1-FSU (Annex 1 Former Soviet Union, i.e. Estonia, Latvia, Lithuania, Russia and the Ukraine), REU (Rest of Annex 1 Europe), PAOC (Pacific OECD and Canada), USA and ROW (the rest of the World), has been developed and used to carry out the analysis. Only emissions of carbon dioxide (CO_2) from combustion of fossil fuels are taken under consideration, the most important human cause of global warming.

A1-FSU energy situation

The energy sector is responsible for a dominant part of the GHG emissions in Russia and the Ukraine. According to the Russian second national communication (UNFCCC, 2000), fossil fuel combustion causes 98.6 percent of the Russian anthropogenic CO_2 emissions, while CO_2 contributes 77 percent to the total GHG emissions. The energy sector would have to play a major role if Russia were to meet stringent GHG abatement targets.

Total secondary energy use dropped from 6.0 EJ to 4.4 EJ in the Ukraine over the years 1992-1995 (IEA, 2001a, b). In Russia, the corresponding drop was from 27.5 EJ to 20.8 EJ (see Figure 1). Natural gas provides about half of the primary energy demand. The other Annex 1 countries in A1-FSU on the other hand are more dependent on other energy sources. Estonia and Latvia are more dependent on oil and Lithuania on nuclear power.



Source: Data from IEA (2001)

Figure 1. Estimated historic primary energy use in A1-FSUnion countries

Historically, the energy intensity, defined as primary energy supply divided by GDP, in the Soviet Union was very high in comparison to other industrialized countries and it rose even further in the 1990s (when economic output fell faster than energy use). One reason explaining why energy use fell faster than economic output in the 1990s is that it takes time for economic agents to adjust their behaviour to new price signals, not only because of capital stock turnover, but also because consumers often do not have an accurate knowledge of their energy use, nor the technical capacity to reduce the use (IPCC, 2001). Energy intensity in FSU (measured as primary energy per gross domestic product (GDP)) was 59 MJ US^{-1} in 1990, and it increased by one third until 1995 (81 MJ US^{-1}). For comparison, the energy intensity in 1995 was approximately 8 MJ US^{-1} in the EU, and 12 MJ US^{-1} in the USA (IEA, 2001a, b). Energy intensity was, however, lower in Former Soviet Union in GDP measured in purchasing power parity (ppp) terms, 30 MJ US$_{ppp}^{-1}$ in 1990 and 41 MJ US$_{ppp}^{-1}$ in 1995.

Despite the drop in energy use in the 1990s there is a need for investment in new equipment. According to Hill (1999) a significant proportion of the power generation equipment is obsolescent. In 1996, for example, 21.5 GW of fossil fuel capacity was operating beyond its expected lifetime in Russia, and this level is expected to increase to some 55 GW (almost one fourth of the total installed capacity) by 2005.

The A1-FSU region is well endowed with fossil fuel resources. Most of these are located in the Russian Federation. A large share of the total export earnings and government revenues are dependent on exports of these resources. Russia produces roughly 15 EJ of oil and 22 EJ of natural gas annually, with approximately 10 EJ of oil and 7 EJ of natural gas being exported, generating export revenues of about 40-50 billion (10^9) US$ yr^{-1}.

Methodology

A global linear programming (LP) energy-economy optimisation model called GET-K has been developed for the analysis (Persson *et al.*, 2003a; Azar *et al.*, 2003). The model has six regions, EU, PAOC (Pacific OECD and Canada), A1-FSU, REU, USA and ROW. The model is composed of three different parts: the supply side, the demand side, and the energy and transport technology system. Energy supply potentials, maximum expansion rates, and the CO_2-emission limitations are all exogenously set. The LP model minimizes the total energy system cost, based on costs for fuel, capital and a discount rate of 5 percent yr^{-1}.

Carbon dioxide emissions can be reduced by:

- decreasing energy demand;
- sequestration of CO_2; and
- switching primary fuel to non-carbon emitting energy sources such as wind, biomass and hydro, and/or shifting from fuels with high carbon-to-energy ratios (such as coal) to fossil fuels with lower carbon-to-energy ratios (such as natural gas).

Reference energy demand

The energy demand in the reference scenarios is derived from linear extrapolations of historic trends for EU, PAOC and the USA. We have used IEA (2001a) *World Energy Statistics and Balances* for the historic trend analysis. Demand is divided into three main categories: the demand for electricity, demand for heat and process heat, and demand for transportation fuels. For each region, we carried out an analysis of how the demand of the three categories has developed since the 1960 (see Figure 2 for the EU and the USA, and Persson *et al.* (2003a) for a background paper). A strong linear relation between energy use and time was found for electricity and transportation fuels and we have extrapolated these trends into the future. The resulting equations are used as reference energy demand scenarios in the model. The heat and process heat demand is assumed to be the same as the present demand.

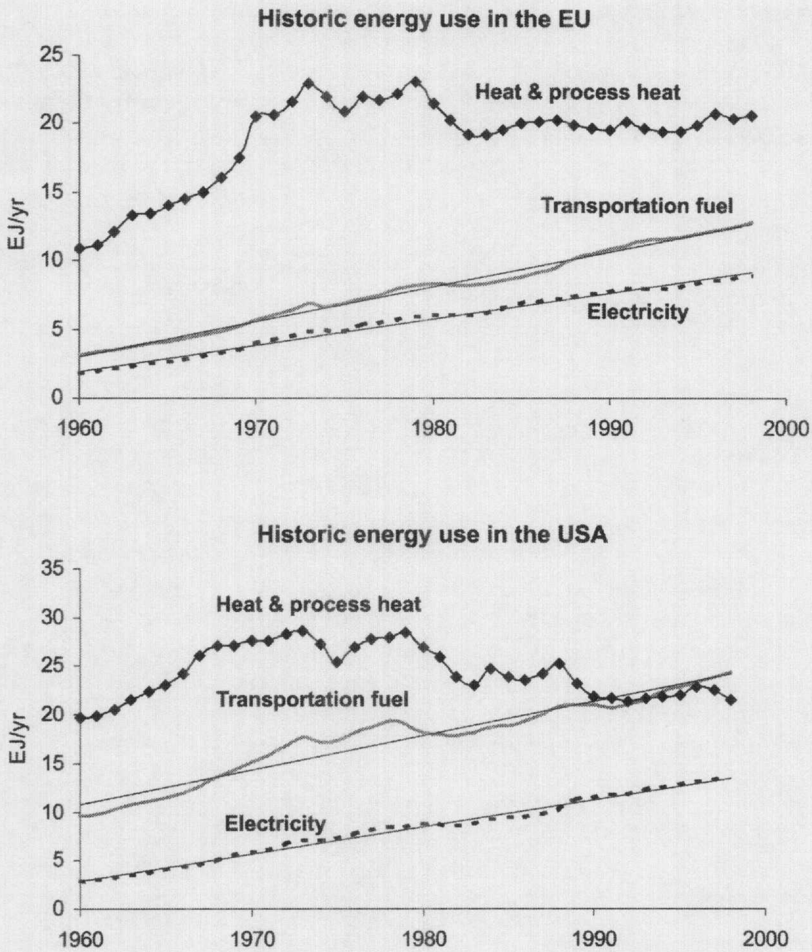
Energy demand for A1-FSU and REU are assumed to follow the assumed GDP growth. GDP in A1-FSU is assumed to grow by 3.5 percent yr^{-1}, energy intensity is assumed to decline at 1 percent yr^{-1} (i.e. the demand grows by 2.5 percent yr^{-1}) in the reference scenario. However Mastepanov *et al.* (2001), Horn (1999) and Jochem (2000) estimate the potential for energy savings to be large in Russia and the Ukraine. Due to the uncertainties related to the demand we have done a sensitivity analysis of how our results will be affected by adopting a different reference demand scenarios for A1-FSU. The energy demand in REU is assumed to grow by 1.5 percent yr^{-1} in the reference scenario.

Energy demand in the abatement scenarios

Our model is linear programming model, with exogenously specified energy demand levels. However, in the real world energy demand can be expected to drop if energy prices increase. We have introduced this feedback into the linear programming model in a simplified fashion, by assuming that energy demand drops by 13 percent for a 200 US\$ tC^{-1} tax by year 2010. This corresponds roughly to a short-term price elasticity parameter of -0.25, which is equal to the elasticity in *Annual Energy Outlook 2002* (EIA, 2002). However, we have assumed the decoupling to be stronger in the A1-FSU. For a tax of 200 US\$ tC^{-1}, the reference energy demand in A1-FSU is assumed to be reduced by 25 percent.

Energy supply potentials

The primary energy supply potentials are region specific and based on literature values (see Masters *et al.*, 1990; Johansson *et al.*, 1993; Moreira and Poole, 1993; Sørensen, 1995; Rogner, 1997; EWEA, 1999). Maximum rates of growth in each primary energy source are set exogenously for all technologies. Nuclear power output is assumed to be phased out at 1 percent yr^{-1} of the 2000 capacity beginning in 2010. Wind power and solar PV capacity are allowed to grow by a maximum 20 percent yr^{-1} (note that this is less than actual growth rates experienced for both technologies).



Note: For the EU, the future electricity and transportation fuel demand is assumed to follow the linear historic extrapolation (the correlation coefficient r^2 is 0.99 for both electricity and transport fuel) while the heat demand is assumed to be constant, 18.5 EJ yr^{-1}, in the reference demand scenario. For the USA, the future electricity and transportation fuel demand is assumed to follow the linear historic extrapolation (the correlation coefficient r^2 is 0.99 for electricity and 0.93 for transport fuel) while the heat demand is assumed to be constant, 20.5 EJ yr^{-1}, in the reference demand scenario

Figure 2.
Historic energy use in the EU-15 and the USA

Results

Reference scenario

The estimated cost of reducing CO_2 emissions to meet the Kyoto commitments is critically dependent on the reference scenario. The higher the growth rates of emissions in the reference case the greater the cost of meeting the Kyoto targets.

The carbon surplus in Annex 1 Former Soviet Union that our model generates with the reference energy demand scenario we presented in the Methodology section is about 220 MtC yr^{-1} (Figure 3). The surplus includes Marrakech sinks and emissions from the energy system. These estimates of the tradable amounts of CO_2 emission permits are in line with other estimates: generally, it is estimated that A1-FSU need to use about 70-90 percent of the allocated emission quota (Mastepanov *et al.*, 2001; Victor *et al.*, 2001; EIA, 2001; Grubb *et al.*, 2001).

Worth noting in Figure 3 is that the aggregated emissions in year 1998 with US participation are 2 percent bellow the Kyoto targets. The reduction of 5 percent from base year to 2010, is thus better described as a +2 percent target from 1998-2010 (since the targets were negotiated in December 1997, and not in 1990). It may here also be noted that the US reduction target from 1998 to 2010 is almost 16 percent (including all Kyoto greenhouse gases), i.e. much more than the 7 percent reduction target that refers to the 1990-2010 (Table I).

In Table I we also see that PAOC has a target of − 13 percent, whereas the EU has a − 5 percent target from 1998-2010. This explains why PAOC is less enthusiastic then EU about the Kyoto Protocol. Overall, the Annex 1 targets without US participation is +14 percent (+16 percent including Bonn Marrakech sinks) over the years 1998-2010.

Modelled reference emissions increase in all our regions until 2010. The carbon surplus in the economies in transition (REU and A1-FSU) has decreased while the other Annex 1 countries are even further away from their commitments. In our reference scenario, EU has to reduce the emission by 135

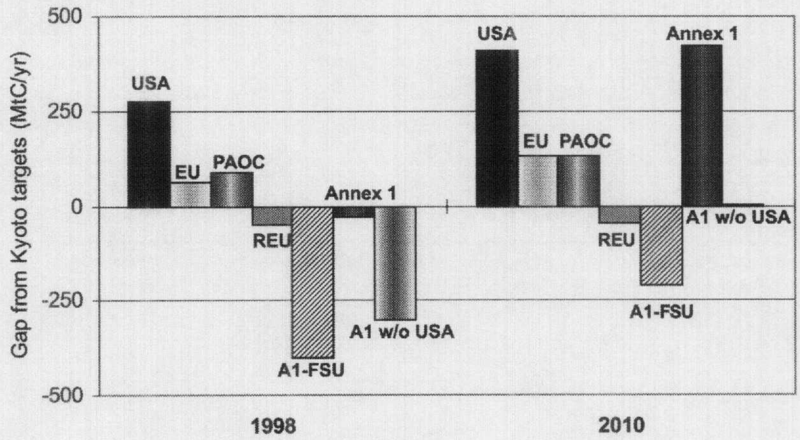


Figure 3.
Absolute gap between CO_2 emissions and the Kyoto commitments in 1998 and 2010

Note: 1998 data are taken from Marland *et al.* (2001), while 2010 numbers are based on our modelled reference scenario. Annex 1 refers to the gap from the aggregated Kyoto commitment for the entire Annex 1 region including the USA and A1 w/o the USA refers to the gap from the aggregated commitment without USA participation. It can thus be seen that the Kyoto Protocol (without USA participation) is met in our reference scenario in the aggregate, and that this is due to the hot air in Russia, the Ukraine and to a much minor extent in Eastern Europe

Table I. The real Kyoto targets. Comparison of emission targets for negotiated base years and 1998 as base year

	Kyoto target: reduction from base year		Real Kyoto target: reduction from 1998 emissions	
	Excluding sinks (%)	Including sinks[a] (%)	Excluding sinks (%)	Including sinks (%)
USA	−7.0	−5.3	−15.7	−14.1
EU	−8.0	−7.5	−5.4	−5.0
PAOC	−3.2	0.8	−12.9	−9.3
EEU	−6.8	−5.6	+32.8	+34.4
A1-FSU	−0.3	2.9	+65.5	+70.8
Annex 1	−5.2	−3.2	+2.2	+4.3
Annex 1-USA	−4.3	−2.2	+13.9	+16.4

Note: [a] Bonn Marrakech sinks included. No values are assigned to the USA; IEA (2001a) value has been assumed (28 MtC)
Source: IEA (2001)

MtC yr^{-1}, PAOC by 130 MtC yr^{-1}, and the USA by 410 MtC yr^{-1} by 2010. The fifth Annex 1 region in our model, REU, is like A1-FSU a potential seller of emission permits by 2010. In our scenario the CO_2 emissions are 45 MtC yr^{-1} less than their allowances in 2010. Thus, the aggregated gap between the Kyoto commitment and the reference scenario emissions by 2010 is approximately 410 MtC yr^{-1} with the USA in the Protocol and around zero MtC yr^{-1} without the USA, i.e. the Kyoto commitments are met without any real emission reductions.

Kyoto no trading

EU, Japan, Canada, Australia and the other Annex 1 countries can meet their targets either by reducing their emissions domestically or by using the flexible mechanisms (clean development mechanism (CDM), joint implementation (JI) and trade in emission permits).

In the no trading case, each Annex 1 region must individually meet its emissions targets without any use of the flexible mechanisms (see Table II). In our scenarios, compliance is generally met by substituting natural gas and wind power for coal in the production of electricity and by substituting

Table II. Emissions mitigation relative to reference emissions, and emissions taxes required to meet the emission reduction requirements in the Kyoto Protocol by 2010 (Bonn Marrakech sinks included)

Region	Emissions mitigation relative to reference to meet Kyoto commitment targets MtC yr^{-1}	Marginal abatement cost to achieve compliance without trading[a] US$ tC^{-1}
USA	410	200
EU	135	100
PAOC	130	125
REU	−45	–
FSU	−220	–

Note: [a] We have rounded the required carbon tax to the nearest multiple of 25 US$ tC^{-1} in order to avoid the impression that the estimations are more precise than they are biomass for coal in the production of heat and process heat. The carbon tax is required to reach levels where these technologies become economically competitive.

Kyoto competitive trading – with the USA

A potentially less costly way of meeting the Kyoto Protocol targets is through the use of the flexible mechanisms. These mechanisms allow each country not only to reduce their emission domestically but also to buy emission permits from other countries, or to carry out joint projects with other countries. If the international permit price is lower than the domestic marginal abatement cost, countries may instead of reducing emissions domestically, buy permits from the international market. This means that a lower overall cost could be achieved.

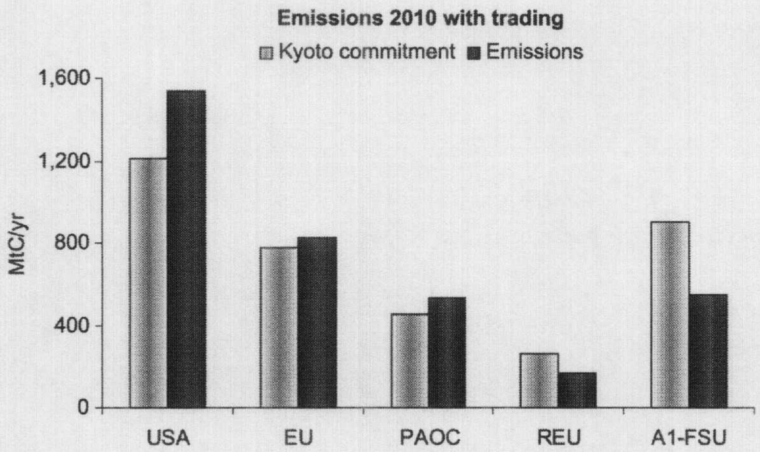
In an Annex 1 trading regime, a country may only emit more carbon dioxide than their allocated emissions rights if another Annex 1 country is willing to sell the corresponding number of permits, thereby forcing the selling region to reduce its domestic emissions below the required commitment. This is modelled as if a common carbon tax were applied to all Annex 1 regions to meet the aggregated Annex 1 emissions target.

We further assume the trading market to be competitive, i.e. suppliers and buyers of permits are numerous and no single permit seller can affect the price received by withholding permits from the market or demand a price over the optimum where the demand and supply for permits equilibrate.

Marginal abatement costs are lower in EU, PAOC and USA with Annex 1 trading than in the no trading scenario. The permit price to bring the aggregated Annex 1 emissions into compliance with the Kyoto commitments is estimated to be around 70 US$ tC^{-1}.

However, this number is not directly comparable to the marginal abatement costs in Table I since the total amount of carbon abated is higher in the no trading case than in the trading case (in the no trading case all countries meet their targets and A1-FSU and REU are 265 MtC yr^{-1} from their target). Hence, arguments that you should not buy hot air from Russia and the Ukraine cannot be challenged on the grounds that this would not be a cost-effective strategy (since two different overall caps are compared). This observation is particularly important in the case where the USA does not participate in the Protocol.

In the Annex 1 full trading scenario, regions are included that have mitigation options with lower costs than the EU, USA and PAOC for sale, thereby the marginal cost to meet the commitments in these countries are lowered. A transfer of emission permits from the countries in economic transition to the modern industrialized countries, especially from A1-FSU to the USA would take place (Figure 4). The USA, for example, would purchase approximately 325 MtC $yr^{-1}$of permits by 2010.



Note: Annex 1 FSU and REU sell emission permits, i.e., their emissions are lower than the Kyoto commitment, while the USA, EU and PAOC buy emission permits

Figure 4. Annex 1 CO_2 emissions in 2010 by region and Kyoto commitments – competitive Kyoto Protocol trading with the USA

The A1-FSU revenues from this trading are about half the present revenues from the export of natural gas and oil. A1-FSU sells in this scenario about 350 MtC yr^{-1}, generating revenues about 25 billion US\$ yr^{-1}.

Kyoto competitive trading – without the USA

As in the previous section, markets for emission permits are assumed to be competitive, but the USA is assumed not to ratify the Protocol.

The US decision to opt out from the Kyoto Protocol results in a situation where the largest potential buyer of emission permits disappears. A lower demand for permits, results in a lower permit price. In Figure 5, we show our modelling results for the emissions in 2010 for each region compared to the Kyoto commitment for each region. In our reference scenario, total emissions in 2010 for the Annex 1 region (without the USA) is roughly as large as the Kyoto target and therefore the required carbon tax, or the permit price, drops to close to zero US\$ tC^{-1}. The transfer of emission permits goes from the Economies in Transition to the EU and PAOC, which otherwise would have had to reduce their emissions by approximately 265 MtC yr^{-1} from the reference emissions during the first commitment period.

The revenues from trading would decrease close to zero in the Russian Federation and the Ukraine as a result of the decrease in permit price.

Kyoto without the USA – A1-FSU as oligopolists

Russia and the Ukraine, can be expected to be the dominant sellers of emission permits in 2010, as previously shown. Thus, Russia and the Ukraine have strong incentives to act as oligopolists, so as to avoid that permit prices fall (since Russia and the Ukraine belong to the same region in the model we have

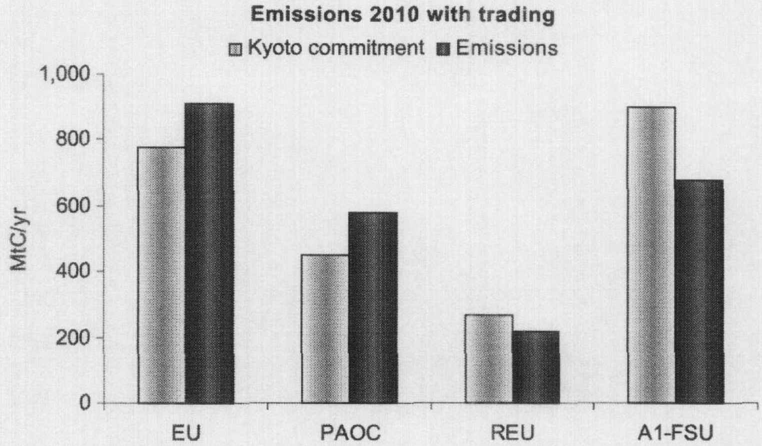


Figure 5.
Annex 1 CO_2 emissions in 2010 by region and Kyoto commitments – competitive Kyoto Protocol trading without the USA

Note: REU and A1-FSU sells emission permits to the EU and PAOC

modelled this case as a monopolistic scenario). A1-FSU countries could thus choose to sell less CO_2 emission permits than in the competitive trading situation and thus increase the permit price.

In Figure 6, we have plotted the sales of emission permits as a function of the carbon permit price. By withholding emission permits, A1-FSU can increase the permit price. The revenues to Russia and the Ukraine are given by price times quantity sold and this is also illustrated in the graph. If no CO_2 abatement policies are implemented in A1-FSU, these countries can sell the difference

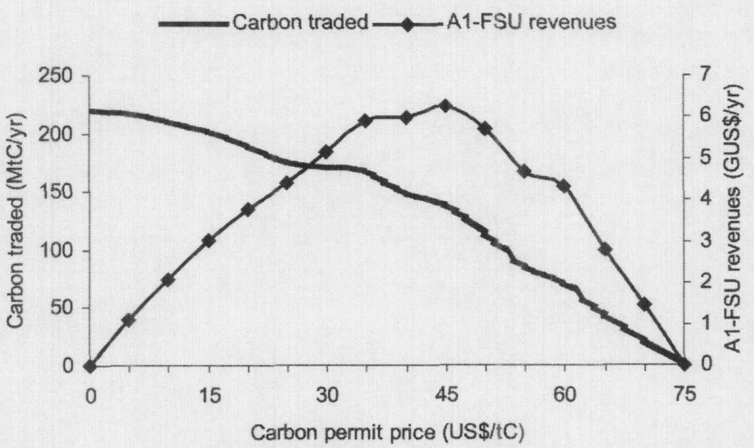


Figure 6.
A1-FSU revenues from trading in GUS$ yr^{-1} (dotted line) and the amount CO_2 traded in MtC yr^{-1} (no dots) as a function of the carbon dioxide permit price

Note: A1-FSU sets the permit price at 45 US$ tC^{-1}, total revenues will be maximized at 6.3 billion US$ yr^{-1} (right axis), and a total of 140 MtC yr^{-1} (left axis) will be sold. Note that around 80 MtC yr^{-1} can be banked in this case for future commitment periods, but we have not considered the value of this (see next Section) between their reference CO_2 emissions and their commitment, i.e. the hot air, about 220 MtC yr^{-1}, but then the price of the permits would basically drop to zero (this is the competitive scenario presented in the previous section, and could materialize if the governments in Russia and the Ukraine would allocate emission rights freely to companies in their countries and if they would be allowed to sell these rights internationally without any restrictions). The scenario shows that A1-FSU is maximizing its revenues when the permit price is around 45 US\$ tC^{-1} and they would then sell approximately 140 MtC yr^{-1}. The revenues end up at approximately 6.3 billion US\$ yr^{-1} from 2008 until 2012. This is about 15 percent of the revenues to the present Russian national budget.

It should be noted that this scenario would bring about real reductions in the remaining Kyoto regions. Total emissions in the annex 1 region (without the USA) would be 80 MtC yr^{-1} lower than the aggregated Kyoto target.

Finally, it may also be noted that if the permit price increases to 75 US\$ tC^{-1}, then EU, PAOC and the rest of Europe would, in our model, would not have any economic incentives to buy permits from A1-FSU.

It is assumed that the A1-FSU countries will act to maximize their revenues during the first commitment period, and future commitment periods are not considered.

The impact on trade and permit prices of early decisions on subsequent commitment period targets

In this section, we analyse if negotiations and decisions about future emission allowances (assigned amount units (AAUs)) could prevent the permit price from collapsing to zero during the first commitment period. It is assumed that banking of the assigned amount units is allowed and that the allowances are allocated according to a contraction and convergence approach. All regions are assumed to have equal per capita amounts of emission permits by 2050, about 0.7 tC $capita^{-1}$ yr^{-1}. Before 2050, each Annex 1 region is allocated per capita emissions allowances that follow a linear trend from their Kyoto target towards the equal per capita allocation by 2050 (the US allowances follow a linear trend 15 percent above their 1990 levels in 2012). In Figure 7, we show our prescribed allocation of emission rights for the different regions on a per capita basis, and it is seen that the USa has the toughest reduction challenge (in both absolute and relative terms) in the long term (despite the generous distribution by the first commitment period).

A1-FSU countries, for example, should reduce their emissions by approximately 2.3 percent yr^{-1} during the 2020's, 2.9 percent yr^{-1} in the 2030's and so forth under this scenario. It can be argued that these reduction targets might be too stringent. But, if we shall stabilize the climate, the CO_2 emissions might have to be reduced to per capita levels prevailing in the less developed countries today by the end of this century (Azar and Rodhe, 1997). This means that the total emissions in the Former Soviet Union might have to

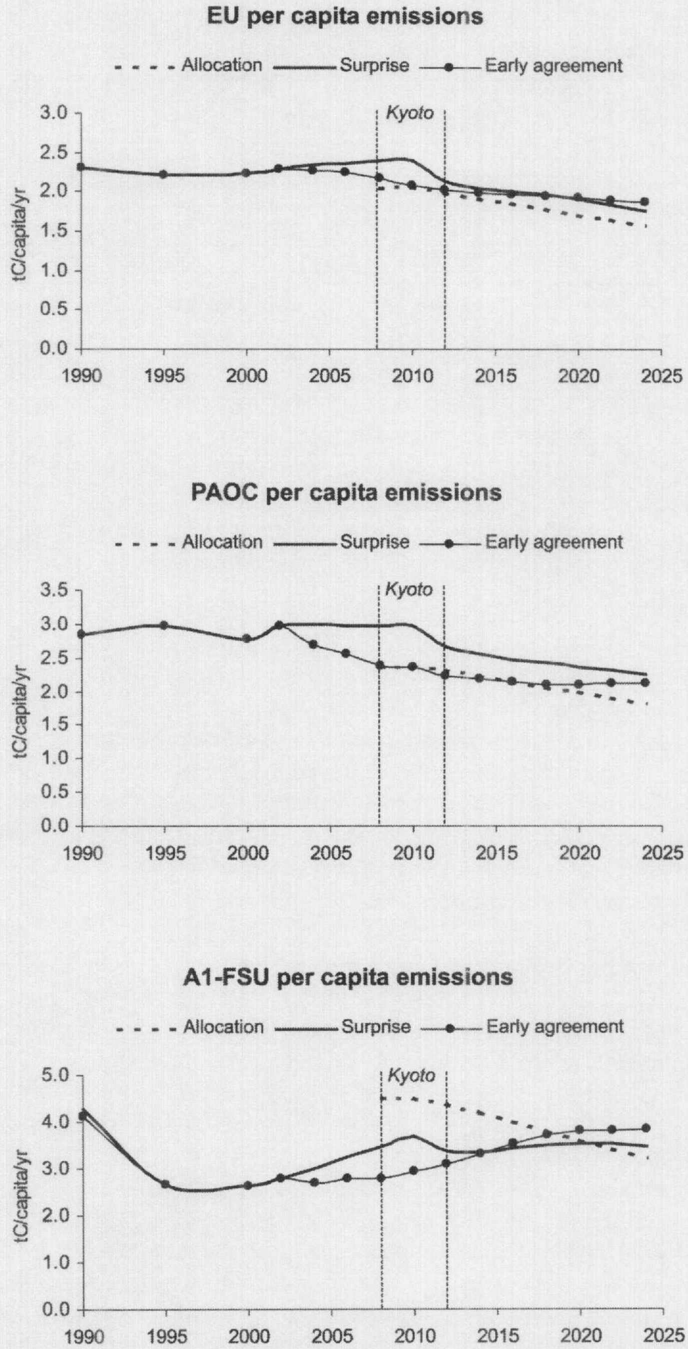


Figure 7.
The effect of negotiation timing of the second commitment period on the CO_2 per capita emissions in the regions

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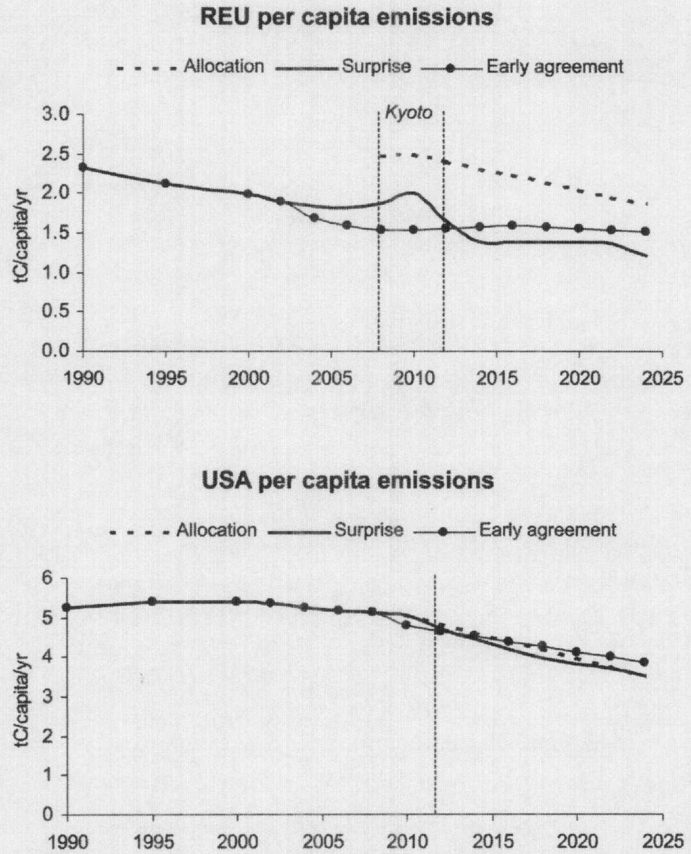


Note: In the *surprise* scenario, the Kyoto commitments are met with large trades in hot air. Adjustments to the emission allowances in the second commitment period begin in 2012. In the *early agreement* scenario, adjustments to the more stringent subsequent targets are carried out already during the first commitment period. This means that more reductions take place in the first Kyoto period and almost no hot air is traded. The allocation of emission allowances in the second commitment period is based on a contraction and convergence approach. The USA is assumed to have emission targets after the first commitment period

Figure 7.

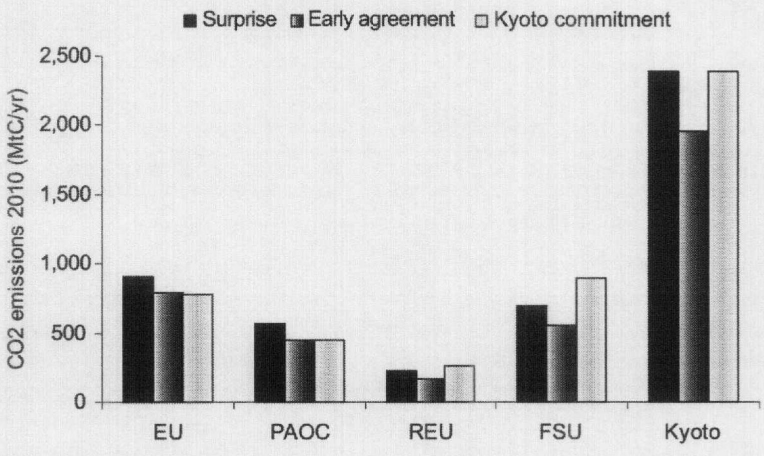
be reduced by 50 percent until 2050 (for a more detailed discussion about allocation of emission permits see Persson and Azar, 2002; Persson, 2003). Population estimates are taken from *UN World Population Prospects* (UN, 2000), median variant.

Two scenarios are compared, Figure 7. The first scenario, which we refer to as surprise, assumes that emissions until 2012 follow the CO_2 emission profile in the competitive trading scenario (see section about competitive trading without the USA.). The total cost to bring the aggregated emissions into compliance with the first commitment period targets is minimized assuming no oligopolists tendencies and, hence, the permit price falls to basically zero. After the first commitment period, the aggregated emissions are assumed to be in compliance with the subsequent period emission allowances.

The second scenario, designated as "early agreement", assumes that the regions are aware of the future emissions allowances before the first commitment period begins. The total cost to bring the aggregated emissions in compliance with the allowances in this case is minimized over the entire period (2000-2050).

The same energy demand is imposed in both scenarios (since subsequent commitment periods are analysed, the previously used carbon tax/decoupling relation is not useable) and banking of emission permits is allowed. It is recognized that both the surprise and the early agreement scenario are extreme variants. In the real world, agreements have to be made earlier than 2010, but the extreme variants clarify the benefits of early decisions.

Figure 7 shows the development of the different regions' per capita emissions for the two scenarios. Due to the knowledge about the more stringent emissions targets during the second period, the per capita emissions by 2010 are lower in the early agreement scenario. The EU is still not in compliance with their emission commitments domestically. However, the purchases from trading by 2010 are reduced from 135 MtC yr^{-1} to about 10 MtC yr^{-1} in the EU (see Figure 8). PAOC is in compliance with the Kyoto commitments in the early agreement scenario. Thus, the aggregate abatement of emissions is more than required in the Kyoto Protocol. It may also be noted that the USA starts to abate emissions already during the Kyoto period.



Note: The aggregated abatement of emissions is more than required in the Kyoto Protocol when the future emission allowance is known before the first commitment period

Figure 8.
CO_2 emissions by 2010 for each region and Kyoto commitments – competitive trading without the USA

Knowledge about future emission commitments could thus be an incentive to reduce the emissions during the first commitment period in all regions since all regions benefit from acting early so that they are in a better position to meet more stringent later targets. Even Russia and the Ukraine have incentives to act, and thereby avoid selling permits at too a low price. The same is evident for the USA, even if they only join the protocol after 2012.

If agreements on future assigned amounts units are delayed (the surprise scenario), countries may be reluctant to reduce their emissions now since that could be turned into an argument in favour of more stringent subsequent emission reductions targets. If, on the other hand, decisions about future abatement targets are made soon, and banking is allowed, governments can act now without being concerned that lower emissions in the first commitment period (2008-2012) would be used as an argument to reduce the assigned amount unit to that country. In the early agreement scenario, we estimate that the required marginal abatement cost is around 130 US$ tC^{-1} in 2010. The marginal abatement cost increases, by 2020 it is estimated to be about 215 US$ tC^{-1} in the early agreement scenario which could be compared with 340 US$ tC^{-1} in the surprise scenario.

Sensitivity analysis

Because of the substantial amounts of uncertainty that surround scenario studies, we have performed a sensitivity analysis in order to identify the sensitivity of our results with respect to different parameters and assumptions, such as the size of hot air, and maximum expansion rates of primary energy supply technologies. In this section, we offer a summary of the results from our sensitivity analysis. For each result section except for the last, we have changed the decoupling factor of energy demand from GDP in A1-FSU from 1 percent to 0.5 percent yr^{-1} and 1.5 percent yr^{-1}, respectively, and increased or decreased the exogenously set maximum expansion rates on primary energy supply by 20 percent.

The marginal abatement costs are dependent on the emissions in the reference scenario. Generally, the amount of CO_2 that must be abated increases with higher energy demand in A1-FSU, and with a reduction of the maximum allowable expansion rates (high expansion rates allows a faster substitution of natural gas for coal (see Table III)).

Russia and the Ukraine have strong incentives in all scenarios to act as oligopolists. The optimal permit price for A1-FSU ranges from 40- 60 US$ tC^{-1}, while the PAOC, REU and EU buy 85-175 MtC yr^{-1} during the first commitment period for the above mentioned changes of the parameter values. The corresponding revenues from the trading range from 4-11 GUS$ yr^{-1}.

Region	Emissions mitigation required to meet Kyoto commitment targets MtC yr^{-1}	Marginal abatement cost to achieve compliance: Domestically US$ tC^{-1}	Trading US$ tC^{-1}	Trading w/o the US US$ tC^{-1}	A1-FSU oligopoly US$ tC^{-1}
EU	131-184	75-125			
USA	414-574	175-225			
PAOC	131-141	125-150			
A1-FSU	− 242- − 32	0			
REU	− 72- − 45	0			
Annex 1[a]	404-812		50-75		
Kyoto[b]	− 12-238			0-25	40-60

Notes:
[a] Annex 1: the aggregated emission gap from the Kyoto commitment for allannex 1 countries
[b] Kyoto: the aggregated emission gap from the Kyoto commitment for Annex 1 countries without the US participation

Table III. Emission mitigation and marginal abatement costs required to meet the Kyoto target (Marrakech sinks included)

Conclusions

This paper has analysed the economics of the Kyoto Protocol. Four issues have been examined:

(1) the carbon permit price with and without Annex 1 trading with the USA ratifying the Protocol;

(2) the carbon permit price with competitive Annex 1 trading without the USA ratifying the Kyoto Protocol;

(3) the carbon permit price without the USA ratifying the Protocol and with Russia and the Ukraine acting as oligopolists; and

(4) how early decisions on targets and the allocation of emission allowances for subsequent commitment periods could affect abatement policies and permit prices during the first commitment period.

The permit price with the USA in the Kyoto Protocol with free trading of emission permits is estimated to be 50-100 US$ tC^{-1} and the total revenues to the Former Soviet Union during 2008-2012 amount to about 25 billion US$ yr^{-1}. However, should the USA remain outside the Protocol the permit price is expected to be much lower (since the overall reduction requirement drops by perhaps as much as 400 MtC yr^{-1}). The permit price without the US in the Protocol could actually approach zero (the overall target is met by selling excess emission permits in Russia and the Ukraine to non-complying countries/regions). Under the assumption of a faster economic recovery than in the base case in Russia/Ukraine, the amount of hot air would decrease and actual emission abatement would become necessary, and the marginal abatement cost might rise to perhaps 25 US$ tC^{-1}. The Russian and Ukrainian potential revenues from the trading could be eliminated or greatly reduced due to the withdrawal of the USA from the Protocol.

Russia and the Ukraine could, however, restrict the supply of emission permits and thus increase the permit price and their revenues. Annex 1 Former Soviet Union could, with oligopoly tactics, increase the price to around 50 ± 10 US$ tC^{-1} by withholding emission permits and increase their revenues to 4-11 billion US$ yr^{-1}.

Two distinct futures can be envisioned, of which neither is attractive nor likely. First, the permit price drops to near zero levels and the Kyoto Protocol would be met to a very large extent through the purchase of hot air from Russia/Ukraine. This is hardly an attractive future for EU or FSU. The possibility that the Kyoto Protocol could be met almost entirely through the purchase of hot air is, or at least could be seen as, worrying for all environmentally concerned governments and scientists. Not only would this scenario mean that no real reductions are implemented, but also it would mean that the credibility of emission trading strategies as part of any international efforts to deal with the climate problem would drop to zero.

The second alternative, which might at first sight seem a reasonable strategy for governments in the A1-FSU, would be to hold back substantial amounts of CO_2 emission rights so as to increase the permit price and increase their revenues. This would perhaps be attractive for Russia and the Ukraine but less so for governments in the remaining Annex 1 countries. For policy makers that are concerned about climate change, transferring billions of dollars without net emission reductions is not likely to be acceptable, and an alternative strategy has to be developed.

There are several strategies that would make sure that real abatement efforts are carried out, and these need to be looked at more carefully:

- Do not to buy emission permits (assigned amount units, AAUs) from Russia or the Ukraine. Clearly, the targets for the EU can be met without the use of flexible mechanisms (as our modelling efforts and many others show), and this would send a clear signal to the world that climate mitigation and economic development are compatible (see Azar and Schneider, 2002).
- Carry out joint implementation projects in Russia where actual reductions would take place.
- Develop the so-called Green Investment Scheme (Tangen *et al.*, 2002), which is a middle form between joint implementation and emissions trading. The scheme has been proposed by Russia and deserves more attention before it could be considered an acceptable strategy. In particular, one needs to make sure that the revenues are actually re-invested into real abatement projects. But once such controls are put in place, one might be much closer to joint implementation projects.

- Negotiate more stringent targets for subsequent commitment periods. This would create incentives for early abatement in all regions including the USA, and in top of that banking of hot air in the A1-FSU.
- Work to convince (through the use of both carrots and sticks) the USA to rejoin the treaty.

Governments in Russia and the Ukraine are aware that there are strong demands in Europe and elsewhere that Kyoto leads to "real" emission reductions. For this reasons, there is a fair chance that constructive solutions will be implemented so as to avoid that CO_2 prices drop to very low levels (Grubb, 2003).

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